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14. ABSTRACT
Gliders carried out four surveys in three regions of the archipelago (Figs. 1-2). During June-July 2007, one glider surveyed the Bohol Sea and the other the northeastern Sulu Sea (Fig. 1). The Bohol Sea survey extended from the Surigao Strait opening at the northeastern end of the sea to the Dipolog Strait at the western end. The Bohol glider was directed along and across the model-predicted transport path between the Pacific and the Sulu Sea. The glider also crossed the northern boundaries of the sea on either side of Bohol Island. The glider in the Sulu Sea followed tracks across the southern opening of the system of deeper straits connecting the SCS and Sulu Sea. The Sulu glider also completed a track across the Panay Gulf mouth between Panay and Negros Islands.

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Glider Surveys of Philippine Archipelago Seas

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LONG-TERM GOALS

This study contributes to long-term interests in understanding:

- How physical processes in a tropical Western Pacific archipelago's straits and seas are forced by the perimeter (pressure gradients, tides, other impinging variable currents) and locally (winds, surface buoyancy fluxes, rivers).
- The Philippine archipelago's mass, momentum, and energy budgets.
- How an archipelago's geometry impacts currents and thus transport and waves entering from the perimeter.

OBJECTIVES

The objectives of the glider-based observational program are:

- Observe mean and variable contributions to archipelago boundary forcing over a several month period.
- Explore interaction between currents and topographic barriers (e.g. Apo Reef, Mindoro and Panay headlands).
- Observe diurnal isopycnal displacements and strain.
- Examine the spatial structure of the sea's response to Mindoro's wind jets.
- Contribute observations to assimilation models.
- Survey the sparsely-sampled Bohol Sea, crossing all boundaries with straits and following Pacific-Sulu transport exchange. Look for responses to remote forcing from the Pacific.

APPROACH

Glider-based observations can reveal kilometer-scale processes in the Philippine archipelago's straits and seas. PhilEx's goal was to improve understanding and prediction

of these varied smaller-scale processes occurring in the archipelago's interior as a result

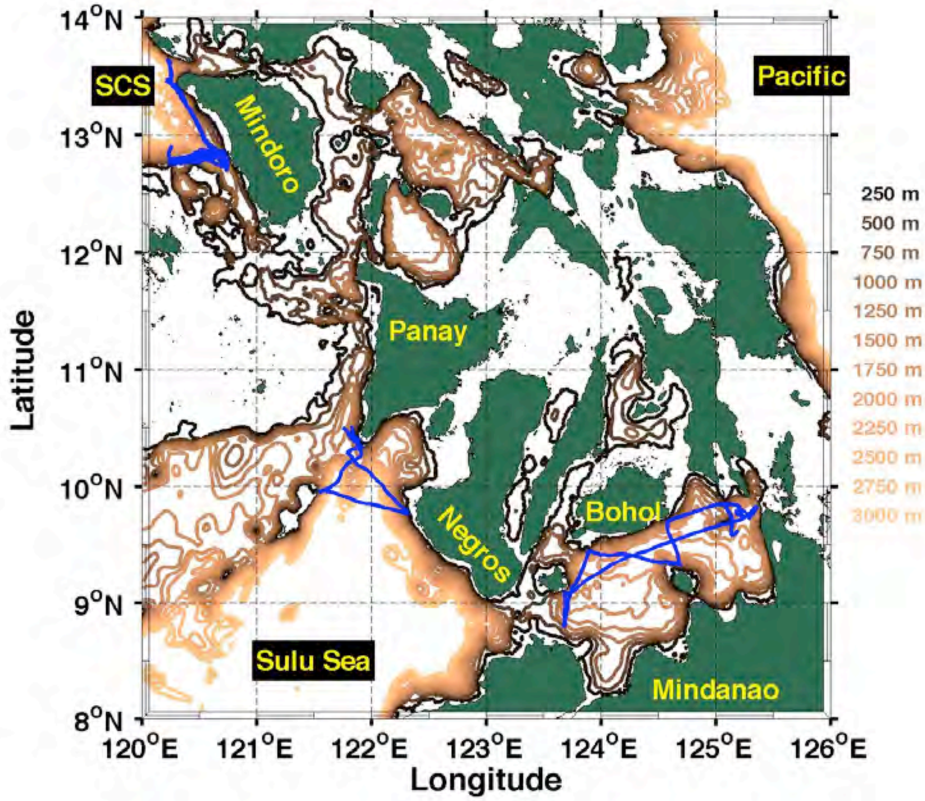

Figure 1. Gliders traveled along the blue tracks in the Philippine archipelago. The glider in the southeastern quadrant is in the Bohol Sea, situated between Bohol and Mindanao Islands. The glider directed along the west side of Mindoro Island reached as far north as Lubang Island, crossing the Verde Passage. The region west of Mindoro and south of 13^{o}N is shown in ***Figure 2.***

of larger-scale perimeter or local surface forcing. *In situ* observations from the archipelago interior when added to observations from the perimeter and remotely-sensed observations could be used in an assimilation model to enhance prediction of the interior. The Philippine archipelago's perimeter is forced by several sources with varying timescales: pressure gradients associated with the general circulation, tides, Kuroshio and Mindanao Current variability, Western Pacific eddies and planetary and Kelvin waves, and Ekman transport (Yaremchuk and Qu 2004; Farris and Wimbush, 1996; White and Tai, 1992). A topic of investigation is how this perimeter forcing propagates into the interior and generates smaller-scale currents. Larger-scale monsoonal winds are funneled through the Philippine mountains producing smaller-scale surface forcing over the straits and seas. For example, wind jets and wakes in the lee of Mindoro and Luzon Islands create eddies in the South China Sea (SCS) (Pullen et al., 2008). Seasonal heat and freshwater flux (including river input) are also expected contributors to smaller-scale processes. The Philippine interior consists of myriad islands, straits, basins, seamounts, sills, banks, and reefs. Currents from larger-scale forcing that encounter this complex geometry and bathymetry are expected to generate a host of smaller-scale processes

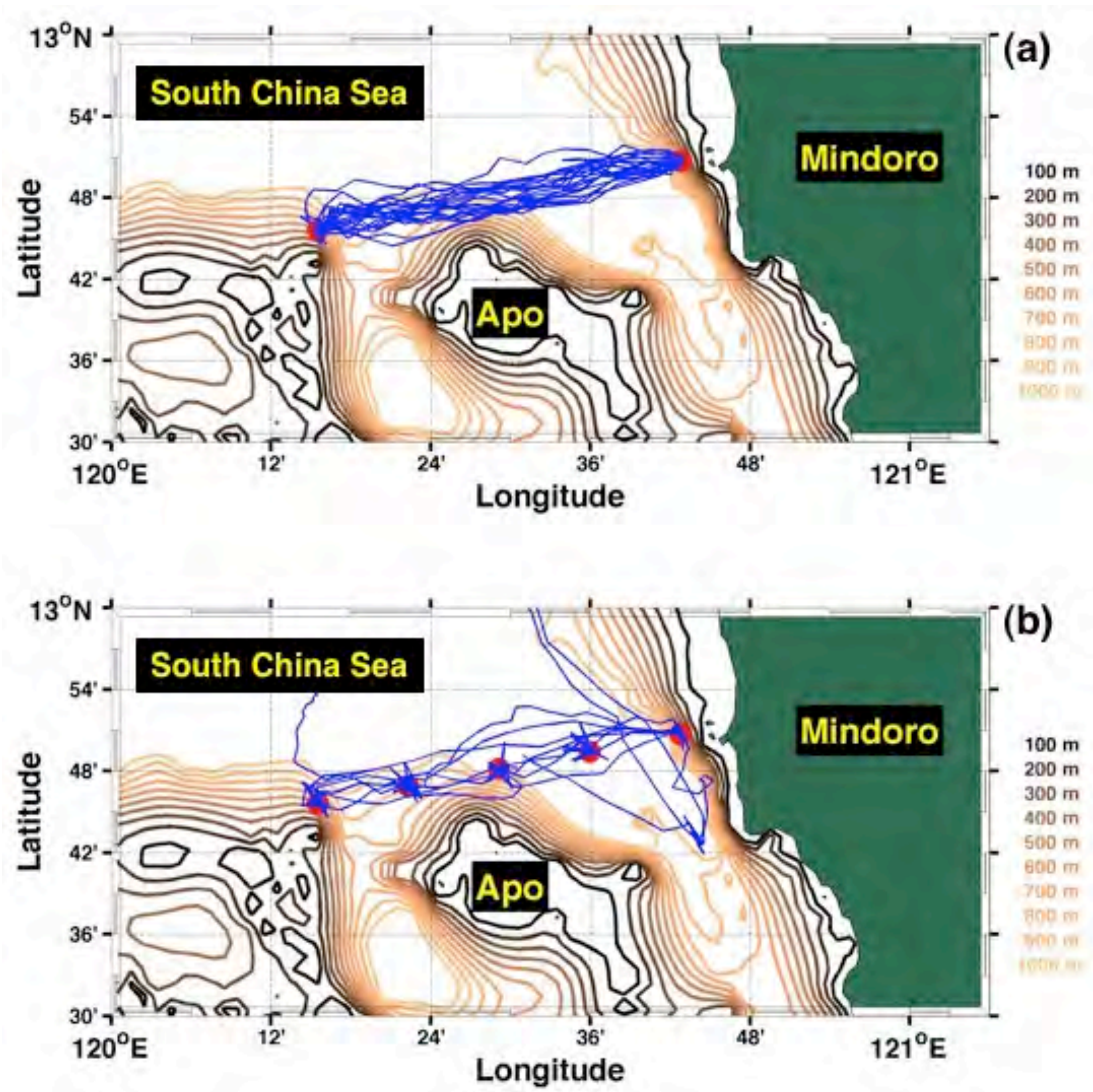

Figure 2. (a) A glider repeated a track north of the Apo Reef and west of Mindoro. The track was aligned to cross the straits on either side of the reef where they open into the SCS. (b) A glider repeated the same track as in (a) and then held position at five stations (red circles) to obtain measurements that resolved diurnal signals.

including flow separations, eddies, internal waves, wind mixing, and turbulent dissipation.

Autonomous gliders surveyed several of these smaller-scale processes during missions lasting up to three months. They provided observations of temperature, salinity, chlorophyll fluorescence, and red and blue backscatter. The gliders dive to as deep as 1000 m, are commanded remotely, and report their measurements via Iridium satellite telephone at the conclusion of each dive. Navigation and knowledge of vehicle buoyancy and pitch angle allows estimation of depth-averaged horizontal currents and

sufficiently energetic vertical currents. Surveys have been aimed at establishing: time-

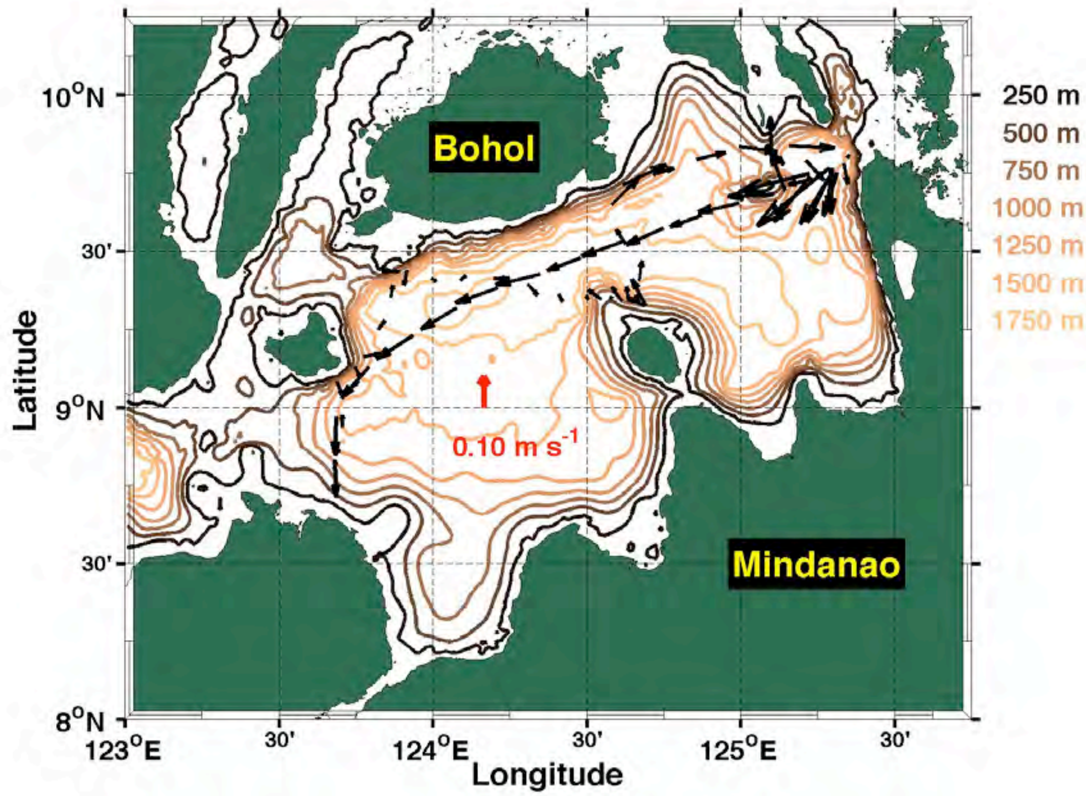

Figure 3. Depth-averaged currents from the Bohol Sea survey. The glider dove as deep as 1000 m, so the currents are an average from sea surface to floor where the bottom depth is less than 1000 m.

mean and -variable structure near a large reef, a sea's response to wind jets and wakes, across-strait structure at the archipelago's perimeter, and a sea's response to Western Pacific forcing. Few observational studies of processes in the Philippines' interior have appeared in refereed literature, so PhilEx and the glider program are exploratory.

WORK COMPLETED

Gliders carried out four surveys in three regions of the archipelago (Figs. 1-2). During June-July 2007, one glider surveyed the Bohol Sea and the other the northeastern Sulu Sea (Fig. 1). The Bohol Sea survey extended from the Surigao Strait opening at the northeastern end of the sea to the Dipolog Strait at the western end. The Bohol glider was directed along and across the model-predicted transport path between the Pacific and the Sulu Sea. The glider also crossed the northern boundaries of the sea on either side of Bohol Island. The glider in the Sulu Sea followed tracks across the southern opening of the system of deeper straits connecting the SCS and Sulu Sea. The Sulu glider also completed a track across the Panay Gulf mouth between Panay and Negros Islands.

During February-May 2008, two gliders repeated a track west of Mindoro Island where the straits on either side of the Apo Reef open into the SCS (Fig. 2). One glider repeated

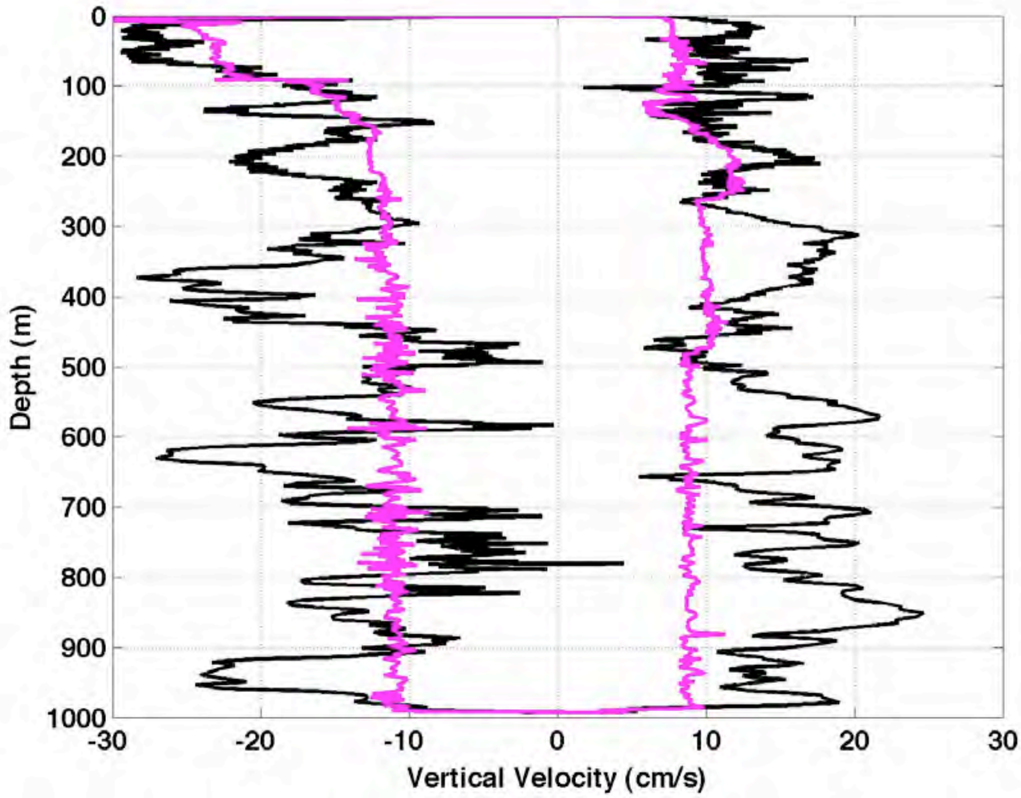

Figure 4. Profiles of actual glider vertical velocity (black, from the pressure sensor) and predicted vertical velocity (magenta, from the flight model) for a complete dive cycle. Their difference is an estimate of vertical current. This dive cycle is from the eastern Bohol Sea close to the Surigao Strait. Intense internal waves caused variations in the glider's vertical velocity and detectable vertical currents.

this 50-km across-strait track continuously, occupying it 21 times (Fig. 2a). The other glider occupied the track 5 times. It then held position at five stations along the track and collected time series of profiles which resolved diurnal signals (Fig. 2b). Each of the stations was held for 24-51 hours with 3-6 hour dive cycles, depending on the local depth.

The glider in Fig. 2b also completed a loop along Mindoro Island's west coast (Fig. 1). The loop's purpose was to look for the effects of jets and wakes produced by winds directed NE to SW through Mindoro's mountain passes and the Verde Passage. The jets and wakes were identified in synthetic-aperature radar (SAR) images and COAMPS-OS model output (similar to that described in Pullen et al., 2008).

Operations were conducted from the R/V Melville and an outrigger canoe. The gliders were deployed while other PhilEx measurement programs were happening on the R/V

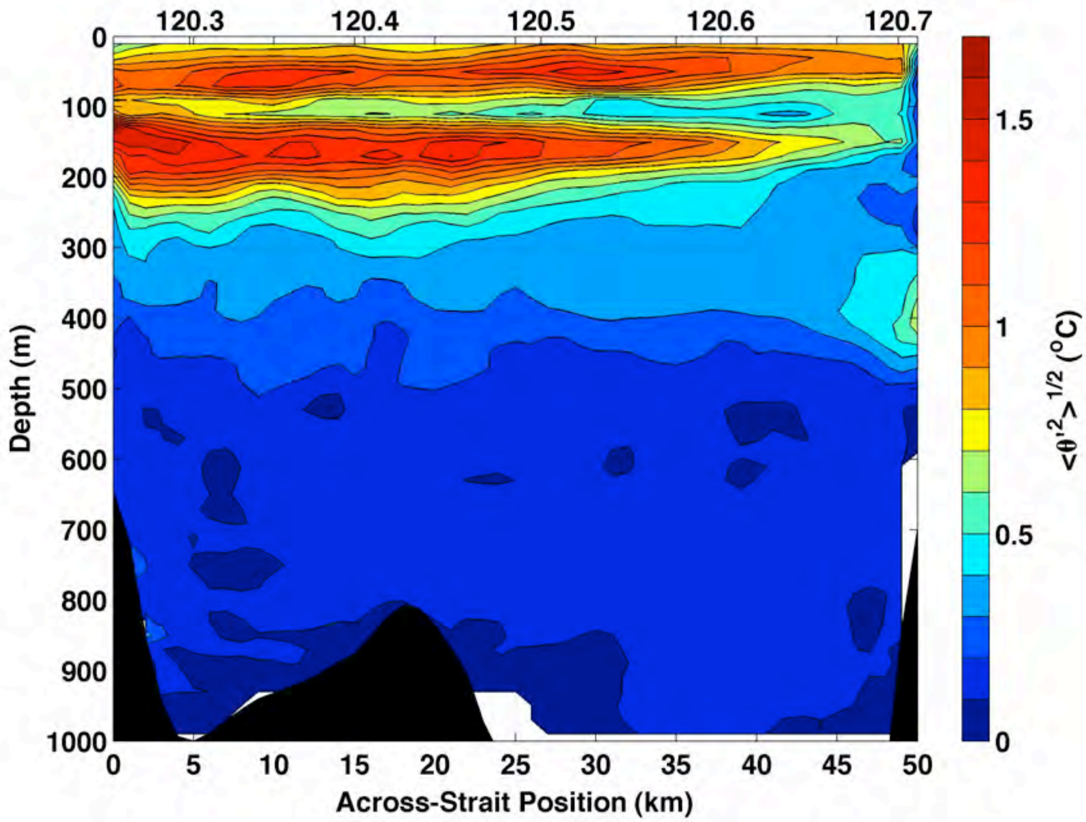

Figure 5. The root-mean-square of perturbation potential temperature θ' for the across-strait section north of Apo Reef. The mean is over all 21 crossings by the glider which followed the track continuously.

Melville. Thus the gliders extended the temporal span of the ship-based measurements.

RESULTS

The Bohol Sea has depth-averaged currents that are forced via its connection with the Pacific (Fig. 3). There is a relatively strong current entering the sea's northeastern end through the Surigao Strait. As the glider traveled westward through the deepest parts of the sea it observed a clear current directed from the Surigao Strait to Siquijor Island (9^o 15' N, 123^o 35' E) where it turns southward. The second pass south of Bohol Island, 12 days after the first pass, shows no evidence of the clear westward current. Thus, currents in the western Bohol Sea can vary on a weekly timescale. At the sea's northern boundary east of Bohol there is a current apparently directed towards the Surigao Strait. Strong internal-wave vertical currents are observed near the Surigao Strait, possibly the result of the strait's intense tides (Fig. 4).

The repeated occupations west of Mindoro (Fig. 2) inform us about mean and variable across-strait structure near a topographic barrier (Apo Reef) during a three-month period.

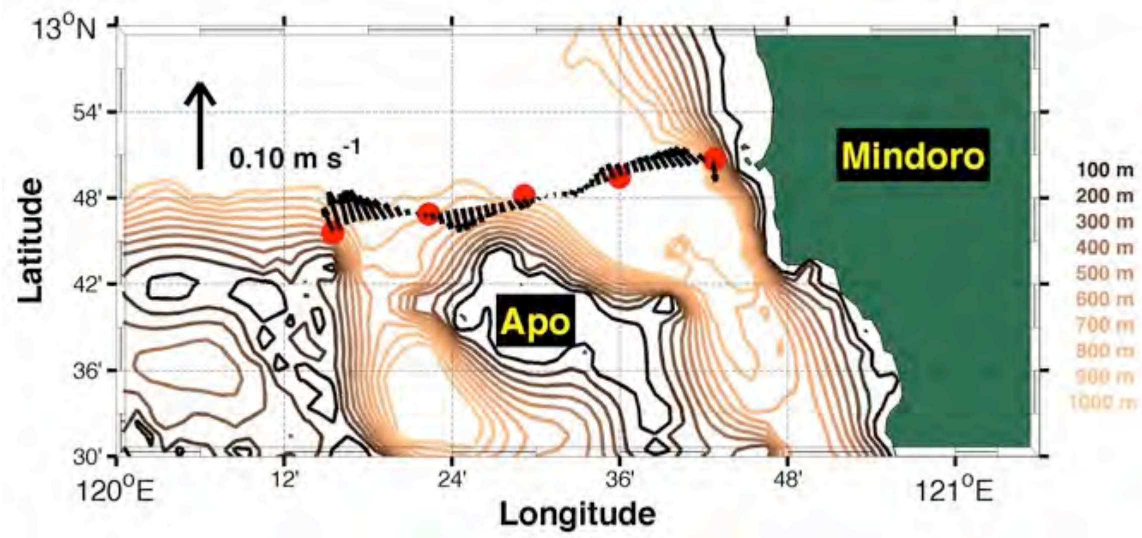

Figure 6. The mean depth-averaged current north of Apo Reef. The mean is over all 21 crossings by the glider which followed the track continuously.

The occupations also provide observations at one of the few passages between the western Philippine archipelago and the SCS. As an example, the root-mean-square perturbation potential temperature is large in two upper-ocean layers, and in the deeper layer it is larger on the western side of the strait (Fig. 5). The mean depth-averaged current is into the SCS at the outer edges of the track and towards Apo Reef in between (Fig. 6). The scale of the vorticity points to the reef having an impact.

Measurements collected by PhilEx gliders have also been assimilated into hindcast/forecast models, providing significant improvements over non-assimilating simulations.

IMPACT/APPLICATION

Demonstrated gliders can be used to monitor depth-averaged currents and density structure at the entrance of a strait.

Demonstrated gliders can resolve internal tide displacements and observe strong internal wave vertical currents.

Demonstrated gliders can operate undamaged and undetected in a heavily fished area for at least three months.

Conducted extended missions with real-time data transfer to Navy and research modeling efforts.

Glider-based observations have been assimilated by a ROMS (Regional Ocean Modeling System) model of the archipelago.

TRANSITIONS

None.

RELATED PROJECTS

This project is part of the larger PhilEx program.

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PUBLICATIONS

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